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A NEW FIELD-LABORATORY METHODOLOGY FOR ASSESSING HUMAN RESPONSE TO NOISE

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16. Abstract

Research during the past twenty years has provided much useful information on human response to noise. Noise standards have been developed and adopted to protect working populations from hearing loss. There are standard indexes to predict speech interference levels and some progress has been made in measuring non-auditory effects. Gross measures of community annoyance with intrusive noises have been made in a number of real environment surveys which indicate that aircraft noise may have to be reduced 30-40 EPNdB before it will generally be considered acceptable. Interview studies, however, cannot provide the precise information which is needed by noise abatement engineers of the variable human response to different types and degrees of noise exposure. A new methodological field-survey approach has been developed at Columbia University to provide such information. The integrated attitudes and experiences of a random sample of subjects in the real environment are obtained by a prior field survey. Then these subjects record their more precise responses to controlled noise exposures in a new realistic laboratory. The laboratory is a sound chamber furnished as a typical living room (18 ft x 14 ft) and subjects watch a color TV program while they judge simulated aircraft flyovers that occur at controlled levels and intervals. Methodological experiments indicate that subjects in the laboratory have the sensation that the airplanes are actually moving overhead across the ceiling of the chamber. It has also been determined that annoyance judgments in the laboratory stabilize after three flyovers are heard prior to a judgment of annoyance. The first threshold of acceptability experiment is now underway.

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PREFACE

For the past three years, a dedicated research staff has been devising a new methodology for measuring human response to noise. This report summarizes the results of their developmental efforts in the hope that other researchers will be stimulated to review their own approaches.

While many individuals contributed to this research effort, a few deserve special mention. Dr. Walter Hoover, Chairman of the Division of Environmental Health Sciences at Columbia University, and James Lewis, Asst. Director of our Office of Projects and Grants, smoothed many of the administrative problems inherent in such work. Dr. Walter Gunn was an invaluable research associate in helping to design the laboratory structure and early methodological experiments. David Fidelman and Michael Harges, Jr. have continued to supply the engineering support and been responsible for the further development of the sophisticated sound and TV systems. Dr. Skipton Leonard, who joined our staff in the past year, has been of general assistance in pre-testing the entire methodology and developing the psychological indices of attitudes and response. Thelma Weiner has been director of our field surveys and processing of all questionnaires. Lastly, Frances Gach has been office manager, who has shielded the rest of our staff from the many necessary but time consuming administrative details.

I. SOME EFFECTS OF NOISE ON THE COMMUNITY

A. Physical Measures of Noise

Practically everyone today is concerned about improving the quality of our environment. After a century of unparalleled and unrestrained technological discoveries, when "bigger and more" were always believed synonomous with "progress", there is now a realization that scientific developments sometimes can be mixed blessings -- Noise which is generally the by-product of new and more powerful machinery is but one of the more recently recognized sources of environmental pollution.

Noise is usually defined simply as unwanted sound. A single noise exposure may be described by a variety of technical indices such as dBA, B, C, D, N, PNL, PNLT and EPNdB. Each of these measures attempts to integrate the different tonal qualities of a complex noise by assigning varying weights to different octave or 1/3 octave bands: EPNdB, an Effective Perceived Noise decibel is a unit of measurement which considers the duration of peak noise level and pure tone elements as well as spectrum shapes. Consequently, it is the most complicated but also the most accurate for certain scientific studies. It should be emphasized that these noise indexes were derived from laboratory experiments, in which the noises judged were devoid of any specific meaning, emotional content or degree of psychological unwantedness. They attempt to express judgements of equal loudness, noisiness or unpleasantness of tones, but <u>not</u> psychological annoyance, which is clearly related to the meaning and emotional content of the noise.

A series of measures have also been devised to describe multiple environmental noises experienced over a time period. Weights are assigned to increasing numbers of exposures by different noise sources during day and night periods. Most of these weights are fairly arbitrary and need more experimental validation. In this report the Composite Noise Rating (CNR) will be used, and it assumes that starting with an Effective Perceived Noise Level, a doubling of number of exposures increases the CNR by 3 units, and that each night exposure equals 10 daytime noise experiences.

The real test of the validity of a composite noise index is its ability to predict measurable "human response". Underlying the general definition of "human response" are two different "value judgements". One attempts to measure only "overt action", the other, "underlying feelings" of annoyance and other physiological effects. Bill Galloway, who has been largely responsible for the development of the CNR index, states...... "the CNR scale...... evaluation of degree of community reaction was based on overt action only". 1/ By that, it is meant that the extent to which individuals actually expressed their annoyance by complaining as individuals, as part of groups, or by instituting legal action to curb the noise is considered the measure of annoyance. The other approach is concerned with an index that describes the mental and physical well-being of people exposed to different noise environments, whether or not they happen to complain about their distress. The distinctions between these two definitions are crucial in evaluating various proposals for noise standards.

<u>It should be noted that any noise index which is solely correlated to overt complaint behavior has been found to be very unstable and to be a poor predictor for any given community</u>. 2/ First, it is generally recognized that relatively few people ever complain about anything; usually about 5 to 10%. Whether or not people who are basically equally annoyed, complain or remain silent at any point in time depends on many interacting factors. Some of these factors are the intensity of annoyance, knowing where to complain, belief that complaint might be effective, confidence in one's verbal and intellectual ability to confront authorities, the social and economic status and

education of the person and his self image, knowledge and contacts with influentials and belief in the support of others in the community, past complaint experience, and the extent to which there is organized opposition to the noise.

A shift in any combination of these human variables can create substantial changes in complaint levels, much to the chagrin of administrators, without any change in the noise environment. Many social surveys in this country and abroad have uniformly concluded that "complaint behavior" is a poor criterion of human response and has a low statistical correlation with CNR measures.

If one examines case histories, where CNR levels are compared to "overt complaints", 3/ the average point where "some complaints" occur is at CNR-90, but the range for "some complaints" is from CNR-80 to CNR-100, a considerable variability. Whether a CNR of 80 or 100 is used in a noise regulation would affect literally tens of millions of additional people and mean billions of dollars in different noise control hardware. As will be seen, there is no simple noise index that can accurately predict community responses.

B. Some Human Effects of Noise

Some of the principal human effects which are related to physical measures of noise are:

1. Temporary and permanent hearing loss.
2. Other physiological responses, such as changes in cardiovascular, endocrine and neurological functions.
3. Interference and masking of speech communication, music and other desired sounds.
4. Interference with rest, privacy and sleep.
5. Psychological annoyance and irritability resulting from a summation of the unwanted disturbances.

Before reviewing some of these human effects, it might provide some sense of realism and perspective if a brief description is given of the current levels of noise to which communities near airports are now exposed. According to a recent Rohr Corp. report, 4/ the biggest 707-320B airplane produces a noise level of almost 118 EPNdB at about 1 mile from a landing touchdown and 116 EPNdB at about 4 miles from start of takeoff, the measuring points in the FAA noise rule. The new jumbo 747's because of their new engine designs, are almost 10 EPNdB quieter on landings and 5 EPNdB quieter on takeoffs. A 10 EPNdB reduction is roughly equivalent to cutting in half the noisiness of a plane. The FAA Noise Rule (FAR 36) for newly designed planes aims at a level of 108 EPNdB for a plane as large as the 747. For a plane about the size of a 707, the FAA noise rule is about 107 EPNdB on landings compared to the actual levels of 118 for landings and 116 for take-offs.

In summary, present older planes are about twice as loud as the FAA rules for new planes. Available evidence clearly indicates that such present exposures are generally unacceptable, and generally create high annoyance in most communities. Dick Broun from HUD, 5/ estimated that there were over half a million people exposed to CNR-105 or greater at JFK New York Airport in 1963. A more recent 1970 estimate advances this total to over 700,000. Likewise, Broun estimated that almost 300,000 residents at Chicato (1965) and 177,000 at Boston (1967) were exposed to these relatively high noise levels. The intense noise levels to which these communities including millions of individuals are now exposed, clearly support their insistent pleas for remedial action.

Dr. Galloway gives us an operational picture of CNR-105. 1/ Only about 5 planes per day at 110 EPNdB (FAA Rule is 108) will produce a CNR of 105. If the volume of operations over a given area is assumed to be about 400 planes per day, of which 15% are night flights, a condition approximating the present JFK situation, a CNR of 105 would require an average noise level of only 85 EPNdB. This level may be within our technical capabilities in a few years, if recent experiments in engine design prove successful. A further reduction to about 75 EPNdB, however, may be required before a level acceptable to most communities is achieved. As will be described in the discussion of survey data presented in Figure 1 and Figure 2, about one-fourth of all moderately predisposed persons express high annoyance, and 80% some annoyance at this exposure. A target of 75 EPNdB is about 45 EPNdB less than the present 707, and 35 EPNdB less than the jumbo 747. To meet these suggested targets, it may be necessary to augment noise reductions due to engine design with other measures, such as land use restrictions, improved techniques in aircraft flight operations and protective acoustic provisions in building codes. Let us now turn to a closer examination of the specific human effects of these aircraft exposures.

1. Temporary or Permanent Hearing Loss

Most research on hearing loss, which formed the basis for the Walsh-Healey Act hearing conservation standards, has involved industrial conditions of a fairly constant noise level during an eight-hour work day, and an assumed quiet residential environment for rest and recovery of the auditory system during the other 16 hours of the day. Less work has been done on hearing loss produced by intermittent noises, characteristic of jet airplanes. However, the Walsh-Healey Act now limits an exposure of 106 dBA to a maximum of 1 hour per day and 100 dBA to a maximum of 2 hours per day. This maximum is the equivalent of about 119 PNdB. As previously cited, some of the communities which are closer than 3-4 miles from major airport runways are now exposed to noise levels that are in excess of these Walsh-Healey limits and may be health hazards. It should be further stressed that for some employed persons these aircraft exposures are superimposed on an already noisy working environment and thus negate the assumptions for recovery conditions. Further study, therefore, is urgently needed of intermittent noise exposures in the total context of a 24 hour cycle of work, recreation and residential living to establish realistic exposure limits that will more adequately protect people from the risk of hearing loss.

2. Other Physiological Responses

With respect to other physiological effects, it is known that noise can trigger changes in cardiovascular, endocrine, neurologic and other physiological functions with correlated feelings of distress. At issue is whether repeated noise-induced disturbances of this nature will ultimately degrade the physical and mental health of humans. Scattered evidence exists to suggest harmful effects, but systematic studies still remain to be performed in this problem area.

There is further evidence to suggest that if the aircraft noise intrusion arouses emotions of annoyance, resentment and fear, that there is less adaption and greater cardiovascular and other physiological reaction. Such intense physiological reactions may have general long-term degrading effects, especially among special populations whose health is already impaired by emotional disturbances, neurologic, cardiovascular and gastro-intestinal disorders. 3/

3. Speech Interference

The most disruptive and widespread effect of noise is masking or the interference with the reception of speech. This interference is a major contributory factor to

problems of aircraft noise annoyance. Social surveys in airport neighborhoods, for example, have found more people to be annoyed from aircraft sounds due to speech interference, either in face-to-face conversations, telephone use, or radio and TV listening, than any other form of noise disturbance. In schools, office buildings and churches, where speech and listening activities are a vital ongoing function, the intrusion of aircraft noise has been decisive in forcing either the closure of the facilities or expensive acoustic treatment for noise control.

Measures for depicting the masking effects on noise, such as the articulation index (AI), and the speech interference level (SIL), are well developed and have been applied to aircraft sounds. One study reports that at comfortable radio and TV listening levels, there is a sharp drop of speech intelligibility or comprehension when the peak level of simulated indoor jet aircraft flyover sounds exceeds an SIL of 68 dB. This value was found equivalent to 76 dBA and a perceived noise level of 89 PNdB. 6/ At this level, each speech interruption from airplanes could last about 20 seconds and if repeated 400 times a day, would total about 2¼ hours of interrupted communication. This noise level (about 90 EPNdB, 400 flights, 15% night) represents a CNR level of about 110, and as will be shown, at this noise exposure, over half of all persons report some annoyance, even though they are most favorably disposed toward the noise - with no feelings of fear and a belief that the noise is unavoidable.

4. Interference with Rest, Privacy and Sleep

All social surveys and practical complaint experiences by airport authorities have found that interference with sleep causes relatively more intense annoyance and hostility toward aircraft noise than daytime interruptions of communications and social functions. 10/ 11/ Consequently, all composite noise indexes place a greater weight or penalty on nighttime flights. What this weight should be, however, has not been agreed upon, and further empirical research is needed to determine the precise relationships between varying numbers of day and night noise exposures and annoyance, sleep interference and other daytime unwanted interruptions. The CNR index assumes that one night-time noise experience is equal to 10-day time exposures.

Concern has been further expressed that repeated arousal from sleep could generally lead to degradation of health, since rest and sleep provide conditions for restitution of body energy and recovery from fatigue. 6/ Persons subjected to repeated sleep interruptions are believed less capable of coping with additional physical and mental burdens. That practically all patients with psychiatric disorders have a history of severe insomnia reinforces these concerns.

It can be further conjectured that the anger from being awakened is even more stressful to the organism than is the fact of awakening, per se, and that, with time, a person may often become "adapted" to or reconciled to the arousal. When the sound stimuli are of a personal or critical significance, however, such as when there is fear of aircraft crashes, then each and every flyover tends to be noticed and must be decoded as a possible threat or safe passage, regardless of how many previous flights were experienced. This persistent perception and evaluation process involves recurring stress and mitigates against adaptation. Actually, it usually tends to increase distress and annoyance with cumulative occurrences over time.

5. Psychological Annoyance and Irritability

The interruption of speech and sleep, as well as non-auditory effects of aircraft noise are generally not considered desirable by most persons, but these interferences

do not necessarily produce equal annoyance or hostility among differently predisposed people. When a number of communities are exposed to approximately the same noise levels, studies conducted in all nations have found considerable variability in reported annoyance among the different communities.

Scientific social surveys in England and the U.S. have found that average annoyance does increase as the noise exposure increases, but differences in noise environments, at best account for only about one-fourth of the total variability in human response. Of even greater importance are the differences in human attitudes, experiences and other social factors. It has been found that from 70-80% more people who have hostile attitudes toward aircraft noise are seriously annoyed by the same noise exposures than those persons who are favorably disposed toward the aircraft operations.

6. Comparative Study of British and American Reports of Annoyance with Noise

A special comparative analysis was recently undertaken of British and American community noise surveys. Figures 1 and 2 will present the highlights of these two studies.

It should be understood at the outset, that social survey data, which are described in these graphs, have both advantages and limitations. They are studies of cross-sections of populations exposed to actual noise experiences and reporting their reactions to both noise and other environmental stresses in the total context of a real environment. Such surveys are best designed to measure the composite feelings of particular populations at specific locations at the time of a survey. Generalizations required for overall policy and planning may use such data, but it should be recognized that the average numbers calculated from such surveys are based on a limited number of geographic areas (four in this report), and that the estimates of noise exposure do not have the accuracy of a controlled laboratory. In the real environment actual noise exposures from hour to hour and day to day vary greatly and survey estimations are a gross procedure. Nevertheless, the following data are believed to be the best available and may be used as guides in assessing community response to airplane noise exposures.

The TRACOR survey was conducted in the United States for NASA in two phases. 7/ Phase 1 interviews were completed in 1967 at four airports, while phase 2 was completed in 1969 at the Boston, JFK-New York and Miami International Airports. For a number of technical reasons, after discussions with TRACOR personnel, it was decided to use only the 2912 interviews from phase 2 in this special analysis.

The second London Heathrow Airport survey 8/ was conducted in 1967 and included 4647 usuable interviews. Fortunately, the American study concentrated on populations residing in high noise exposure environments, while the British design selected most of its interviews in areas of lower noise exposures. When the data from the two surveys are tabulated on a comparable basis, the combination of the results provide the following balanced set of over 7500 observations, more than have ever been available for analysis.

Number of Interviews by Noise Exposure

CNR	British	American	Total
< 96	3221	146	3367
96-99	419	195	614
100-104	539	589	1128
105-109	261	455	716
110-114	105	613	718
115+	102	914	1016
Total	4647	2912	7559

First, a few basic definitions:

Annoyance is defined as a feeling of displeasure associated with the unwanted noise believed to be adversely affecting the individual. "No annoyance" literally means that no activity interference was reported by a person as annoying. In the British study, 6 items were used to develop a 6-point scale of annoyance, i.e.,

Score one point for each of the following:

1. General question - aircraft is annoying
2. Airplanes wake up - very or moderately annoyed
3. Airplanes interfere with conversation - very or moderately annoyed
4. Airplanes interfere with listening to TV or radio - very or moderately annoyed
5. Airplanes make house vibrate - very, moderately or a little annoying
6. Other effects - very, moderately or a little annoying

"High annoyance" was defined as a score of 4 or more, and generally included more than a little annoyance with interference of at least 3 activities and an answer to the overall question that aircraft noise bothers "very much". "Moderate annoyance" includes persons with scale scores of 1-3. The term "Some annoyance" includes both High and Moderate annoyance responses.

In the American study, 9 items, including the British six, were included in the annoyance scale. Each item could be scored in intensity of reported annoyance from 1-5, where 1 equalled none, and 5 equalled very much. The maximum annoyance score, therefore, was 45; 1-9 equals no annoyance, 10-20 equals moderate and 21+ represents high annoyance.

Fear - A belief that the aircraft producing the noise poses a threat to one's safety. The noise connotes an approaching plane and fear is the belief that it may crash into the place where the person is located. As the noise content indicates a safe overflight or departure, the tension associated with the fear is reduced.

<u>Misfeasance</u> - A belief that the aircraft operators have the knowledge and ability to modify the noise produced by the airplanes but choose not to do so for a variety of reasons believed to be insufficient. The achievement of comparability in this variable was most difficult but after careful comparative analysis of responses, it is believed that the two sets of data now generally measure the same factor.

Figure 1 compares the overall "high annoyance" responses for three selected psychological pre-dispositional groups of people living under the same noise exposures. Figure 2 presents a similar comparison but the annoyance response is for total or "some annoyance" which includes high and moderate annoyance.

Those persons included in the solid line, lower curve, represent the group most favorably predisposed to accommodate the noise; they express no fear, and feel the aircraft operators are doing all they can to minimize the noise. Thus, this curve probably represents the minimum level of annoyance responses. It should be noted in Figure 1 that while only about 20% of this most favorable group express "high annoyance" at even very intense noise exposures; as Figure 2 indicates, over half of them express "some annoyance" at exposures of over CNR-100.

The top line in both figures represents the opposite extreme, or the most psychologically hostile group. They can be considered to represent the ceiling in a series of annoyance curves. They report feelings of high fear and high misfeasance. Over half of them indicate "high annoyance" at even low noise exposure levels and almost all indicate "some annoyance" at all noise exposures. The particular combination of these extreme predispositional groups that one happens to select in a sample of respondents determines the average calculated annoyance response for that community. It is very important, therefore, to know the psychological attitudes of a sample as well as the noise exposure, in order to predict levels of annoyance response.

In using the two extreme curves for planning purposes, one implicitly assumes that the worst possible conditions or the most ideal conditions will exist. Neither assumption is probably realistic. That is why the middle curves are included in Figures 1 and 2. They assume that there will always be some residual moderate fear and moderate feelings of misfeasance even after efforts have been made by the operators to reduce the environmental impact of their operations.

The definition of an "Acceptability Level" is clearly a political decision of how many people will be protected and at what level of protection. Not all people can possibly be satisfied if economic and other social and political factors are to be considered. Whether 90%, 80%, 70% or some other number is to be protected must be a government decision. Then the question is: shall our goal be to eliminate only high annoyance, or shall it include protection from moderate annoyance as well. From Figure 1, we see that 1/5 of all moderately predisposed people express <u>high</u> annoyance at CNR levels of less than 96, and almost half at CNR 100+.

Correspondingly, in Figure 2, some annoyance which includes high and moderately annoyed, jumps to 60% at exposures of even less than CNR-96 to 86% annoyance at CNR-100+.

An acceptability criterion is probably somewhere in this range. A level of CNR-95 implies a plane which produces only about <u>75 EPNdB</u> of noise at an airport with the type of operations that exist at JFK, New York. Obviously, much more technical research and development will be required to achieve such goals.

II. A NEW METHODOLOGY FOR ASSESSING HUMAN RESPONSE TO NOISE POLLUTION

A. Background

While there is general awareness that noise pollution must be reduced if the quality of our environment is to be improved, the huge costs involved and the disagreements as to the extent of community annoyance at different levels of noise exposure are impeding the implementation of noise abatement efforts.

It may come as a surprise to learn that it cost the airlines over $200,000 for installing 1½ tons of noise reduction hardware on each of the present 707 and DC-8 airplanes. The cost of developing the 10 EPNdB quieter 747 engines was over 100 million dollars. The proposed additional acoustic treatment of 707's and DC-8's to make them as quiet as the 747's, popularly known as the retrofit program, would cost as much as 2 billion dollars for the existing fleet. Each additional EPNdB of noise abatement will cost correspondingly huge sums of money and there is consequently real concern about the amount of human benefits that varying amounts of noise reduction will actually produce.

Research over the past three decades has produced much useful information on noise propogation and human responsiveness to it. Much more, however, still needs to be learned in order to answer the practical questions posed by noise abatement officials. Some of the contributions and shortcomings of past research will be reviewed and then a new approach that has been developed at Columbia University will be outlined.

The earliest noise research began in acoustic laboratories and concerned primarily pure tones and their properties of equal loudness, masking, attenuation, etc. Obviously, pure tones are devoid of specific meaning or emotional content. Consequently, little attention was ever given to the kinds of volunteers used as subjects other than differences in hearing thresholds, to the physical appearance of the sound room, usually a small IAC chamber, or to the use of tasks by the subjects in the experimental designs. When researchers were asked to look at complex environmental noises resulting from aircraft, highway and industrial operations, they naturally modified the techniques already developed in pure tone research to this more complicated noise pollution problem. The result has been a proliferation of a variety of measures of single noise exposures, such as dBA, B, C, D, N, PNdB and PNLT. Each of these indices attempts to integrate the different spectral characteristics of different sounds into simple units of equal noisiness or unpleasantness. The higher frequencies are usually given greater weight in combining them with sounds with lower frequencies.

The psycho-acoustic experiments used to develop these measures did not concern such matters as prior attitudes of subjects or different experiences with the actual noise source, the realism of the laboratory and the noises judged, or the various activities which the noise might interrupt and thus create feelings of unwantedness or annoyance. 3/ Consequently, these units of noise measurement can not be said to describe units of environmental annoyance, since noise by definition, is unwanted sound and its unwantedness cannot be measured realistically without considering the meaning and emotional content of the noise as well as its effect on interfering with different desired activities.

Starting in 1952, the social survey techniques were first used in this country to try to determine how people in the real environment perceived noise and what psychosocial variables influenced their reactions to these noise exposures. 9/ The

advantage to this approach was to study real people who are representative of actually exposed populations in their normal environments in which noise is but one of many environmental stresses. These early studies and a series of later ones in the U.S. 10/ in England, 11/ Netherlands, 12/ Sweden, 13/ France, 14/ and others, clearly identified the importance of measuring attitudes and experience variables as well as measures of the physical exposure in order to determine differences in annoyance response. It is interesting to note that Dr. Glass recently reached the same conclusion as a result of a series of laboratory studies. 15/ The latest comparative analysis of over 7500 American and British interviews, which has already been discussed (Figure 1 and 2), dramatically illustrates the interaction of only three of the key variables.

The major disadvantages of the survey technique, however, are that data collections are very costly, time consuming, and only gross averages of the very complex stimulus situations are possible. Engineers and noise abatement officials need to know the independent and interacting contributions of the components of a noise experience in order to assess the cost-benefits of specific proposals for noise reduction. The social survey cannot tease out these details. The human being is exposed to a wide range and frequency of physical noise experiences over time resulting from over 100,000 different combinations of physical variables. Some of the basic factors are: 5 different basic types of airplanes, performing at least 3 different operations (landings, takeoffs and circling maneuvers) in different weather conditions, with the person being inside or outside the house and doing different things, such as communicating, sleeping, performing tasks, etc., with different numbers of exposures, ranging from a few to thousands per day and night. Somehow, each person can integrate all of these different conditions estimated to be well over 100,000 types of experiences and express a combined average annoyance response. But, if we want to assess the separate effects of these different types of exposures, it is our belief that a new controlled laboratory methodology is needed. Table 1 presents a simplified model of a physical airplane noise exposure.

B. A New Field-Laboratory Approach

A new research program is underway at Columbia University that attempts to utilize the experiences gained in past field and laboratory studies. Small random samples of residents in the vicinity of JFK Airport in New York City, who are exposed to different real life noise environments have been interviewed in their homes as part of a regular community study. Details have been collected on such personal variables as attitudinal and experience differences as well as reported annoyance and complaint behavior. Sub-samples of those found predisposed to accept or reject given noise environments are being invited to participate in realistic types of acoustic laboratory studies. The laboratory is located at Franklin Square, Nassau County, near the actual residences of the sub-samples of subjects and the experimental environment in the laboratory has been made as realistic as possible. The laboratory, which is an environmental chamber with variable control over the temperature, humidity and noise conditions, is at present furnished as a typical living room in a middle class house. The use of the latest, most sophisticated quadrophonic sound system has succeeded in producing a realistic aircraft noise experience in which the plane appears to fly overhead across the room. Subjects are instructed to participate in a real activity such as watching a color TV program. A variety of controlled noise exposures from aircraft flyovers are simulated in the laboratory and subjects rate each experimental noise in terms of the degree of interference with the activity such as TV watching and listening and also the degree of possible annoyance resulting from the interference. The experimental noise level can be adjusted until reported as acceptable, i.e., no or little interference, no or little annoyance, etc. An analysis of the controlled noise levels, the subjective personal factors, and the laboratory responses will

TABLE 1

OVERALL CONCEPTUAL FRAMEWORK OF AIRCRAFT NOISE EXPOSURES

Eight Basic Physical Variables

Minimum No. Sub classes		
5	A.	5 Types of Planes

4 engine Low By pass
4 engine High By pass
3 engine Low By pass
3 engine High By pass
2 engine Low By pass

3 — B. Operations

a) Landing (specify landing flaps and power - 15^o - 40^o = 8 EPNdB; 30^o - normal)
b) Take-off
c) Maneuvering (circling)

8 — C. Slant Distance - under track and off to side

(landing 3° glide slope - at least 4 groups for 707)

Altitude (feet)	370	750	1500	3000
(meters)	112.8	228.6	457.2	914.4
Lateral distance (miles)	1.15	2.5	5.2	18.5
(km)	1.85	4.02	8.37	29.77
Outside (PNdB) =	115-118	107-110	98-101	87-89

6 — D. Time of Exposure / By Season

Time of Exposure	By Season
a) Day	a) Cold
b) Evening	b) Warm
c) Night	

3 — E. Rate per Hour (Maximum or Average)

20 per hour -- 500 per day
10 per hour -- 250 per day
5 per hour -- 125 per day

3 — F. Position of Subject

a) Outside
b) Inside - windows open
c) Inside - windows closed

3 — G. Ambient Noise

a) High
b) Medium
c) Low

4 — H. Activities

a) Passive Communication - TV, radio
b) Active Communication - Conversation, telephone
c) Tasks - by degree of complexity - concentration
d) Sleep and rest

provide more precise measures of average acceptability and any differences for those with hostile or favorable predispositions to the noise. One of the laboratory noise exposures will approximate the average real life experience of each subject, and the reported degree of interference and annoyance previously reported on the community survey will be compared to the laboratory response. Any consistent differences between real life and laboratory responses can be used as a calibration adjustment to extrapolate laboratory findings to the real world.

The following figures illustrate some of the new realistic features built into the laboratory:

- Figure 3 - shows the hallway - a subject follows to get to the chamber, at the far right.
- Figure 4 - shows the door, opening to the living room chamber.
- Figure 5 - shows the open door looking into the living room. At the left is a shield covering the vault-like double IAC door. Originally, this was uncovered and people expressed fear at being enclosed in the room.
- Figure 6 - shows the closed IAC door, which is done after the subjects are in the room and the wooden door is shut from the inside. Then the shield is removed.
- Figure 7 - shows the interior of the room, which is 18' x 14' and is a triple wall chamber with separate temperature, humidity and noise controls. The ambient noise level is less than 15 dBA. What appears as two windows are fluorescent fixtures covered by plexiglass and drapes. The TV set can be seen on the lower right corner.
- Figure 8 - shows the one-way mirror through which subjects may be observed and filmed for non-verbal behavior.
- Figure 9 - shows the control room and instrument complex. There is a complete sound system including spectrum shapers and mixers so that the sound reproduced in the chamber can be completely controlled. It is estimated that a maximum noise level of over 120 dBA or 133 PNdB can be reproduced in the chamber without significant distortion. We can electronically synthesize a wide range of complex sounds, varying in spectral shape, duration and intensity to test meaningful responses to different proposed engineering modifications to actual sounds.

The sound system includes four Klipschorn speakers, 2 Crown amplifiers and a Crown 4-Channel tape recorder system, B & K 1/3 octave band spectrum shapers, Switchcraft mixers and a Burwen 2000 noise eliminator to minimize tape and speaker hiss. With these components, realistic motion and direction of any external sound sources with a dynamic range of about 110 dB can be simulated. There are also Rudmose audiometers and RF shielding around the chamber for future physiological and telemety studies.

At present, as is shown in the Figures 3-9, the room is furnished with rugs, artificial windows (fluorescent lights behind a diffuser and draperies), a color TV set and couches, chairs and other furniture simulating a middle-class living room. The first experiments involve a series of laboratory and field tests designed to measure differences in perception and annoyance with proposed 727 retrofit packages. The room can be reconstituted to simulate any type of chamber, office, bedroom, etc. and be related to any kind of real activity.

C. Results of Preliminary Methodological Studies

Three experimental studies which were used to develop our laboratory methodology are reported below:

(1)--The first methodological study determined that directionality of an outside sound source is determined primarily by the window openings in relation to the movement of the airplane. When they happen to be aligned, subjects judge the direction correctly.
(2)--The second study demonstrated the overhead effect of the quadrophonic sound system.
(3)--The third study determined that after three exposures to the same stimulus, judgements of annoyance, stabilize, when up to five exposures are presented prior to judgements of annoyance.

1. Directional Study

The need for this study developed from our objective to create a realistic acoustical environment within our sound chamber. Our sound system, with four audio tracks and speakers, is capable of creating virtually any combination of effects. The question then arises, "What are the effects we wish to create?" A simple answer would be "Just record the sounds of a real environment and play them back through our sound system." If this were done, the effects within our chamber might vary in many unpredictable ways. A more scientific approach would be to determine the extent to which people actually decode or perceive real aircraft fly-overs and then recreate these effects in our simulated living room.

What are some of the possible characteristics of the sound of an aircraft which must be present in any reproduction in order for it to sound realistic? Some of the characteristics of aircraft sounds, as heard by a listener inside a house may be as follows:

(1) Loudness changes
(2) Spectrum changes
(3) Doppler shifts, and finally
(4) Directionality and apparent movement

It seemed clear that the first three characteristics could be easily reproducible by a simple monophonic tape recording. However, the directionality and apparent movement of the source (if this is indeed a factor) would require a multi-channel recording obtained either directly or by synthetically controlling the levels of each channel when copying a monophonic recording of the flyover. The question is whether or not it is more realistic to present flyover sounds which seem to have directionality and apparent movement than to present sounds which merely possess loudness and spectrum changes and doppler shifts. In order to answer this question, it was necessary to conduct a controlled experiment in which all non-auditory cues were eliminated.

a) Procedure

Six men and six women, ranging in age from 19 to 45, possessing hearing levels within 20 dB (ISO) of normal hearing, participated in the experiment.

Two houses situated in a residential area directly under a landing flight path to JFK Airport were selected for the experiment. Both houses were of the single story variety

with a brick veneer on the lower section. Front and side windows of the living room were opened during each session.

Subjects were blindfolded with opaqued wrap-around sun glasses and were ear-muffed with Hear-Guard Hearing Protectors (Model 1200) at our laboratory and driven about 20 minutes to the test sites for each session. Since the houses were actually across the street from one another, it was necessary to leave one subject at the first house and then drive the other subject around the neighborhood to disorient him before leaving him at the second house. This succeeded in confusing the subjects about the relative locations of the homes, so that their judgements in the first home would not affect their judgements in the second. Half of the subjects made their first judgements in house A and the other half in house B. A Correct judgement in houseA was left to right, while in house B it was right to left.

Once inside the house, the blindfolds and earmuffs were removed and the subjects were instructed as follows:

"This is a drawing of the house you are in right now and its surrounding area. Here is the room you are in (point to room) and here is your present position (point to position). We have arranged for airplanes to fly over the house or off to the side (point to various directions to indicate). The planes will be flying one of the following paths (show the possible paths on data sheet and illustrate where each would be heard). Your task is to listen carefully to three flyovers, and circle the path on the data sheet which best describes the flights which you heard. If you are not sure, then you must make a guess. Circle only one path. In addition to selecting the flight path, also answer the two questions on this sheet, by checking the appropriate box. You may feel free to stand, sit, or walk around the room, but do not go to the windows where you might see the plane. I will tell you when to start and when to stop."

Three successive judgements (trials) were made by each subject, at which point the blindfold and earmuffs were again put on. The subjects were then driven separately around the neighborhood (blindfolded and earmuffed) and taken to the second house. Once inside, they were relieved of the blindfolds and earmuffs before being instructed again. Three more judgements were made and the subjects were then blindfolded, earmuffed, driven back to the laboratory and given an honorarium of five dollars prior to being released. Figure 10 is a copy of the data sheet used in this experiment. Note that there were eight possible judgements off to the sides of the house and four directly over the house.

b) Results

Table 2 shows a summary of results with both the number of correct judgements and expected frequency for each combination of house, trial, and criterion. The first two columns, labeled CORRECT ARROW, show the number of correct responses and the expected frequencies. Since there were twelve arrows from which to choose, and there were twelve subjects, the expected frequency for each trial is 1. The next two columns, labeled CORRECT DIRECTION FRONT TO BACK, shows responses judged to be correct by virtue of indicating the correct front to back direction regardless of the correctness of the right to left component. Since the possible responses are front to back, back to front, or neither and since there were twelve subjects, the expected frequency is four. The last two columns, labeled CORRECT DIRECTION right to left, shows responses judged to be correct by virtue of indicating the correct right to left direction regardless of the correctness of the back to front component. Again, the expected frequency is four.

TABLE 2

Judgements in Directionality Experiment

TRIAL	Correct Arrow House A	Correct Arrow House B	Correct Direction Front to Back House A	Correct Direction Front to Back House B	Correct Direction Right to Left House A	Correct Direction Right to Left House B
1	1/1	6/1	8/4	11/4	4/4	6/4
2	0/1	6/1	4/4	10/4	4/4	8/4
3	0/1	8/1	5/4	10/4	6/4	10/4

As can be seen in Table 2 almost no one in house A chose the fully correct arrow. In fact, chi-square tests of significance were below the p.05 level for all judgements reported in house A, (correct arrow and correct directions) so that the few correct ones could have been due to chance. All of the correct judgements in house B, however, were clearly statistically significant and below the p.01 level. About half of the subjects in house B were actually able to circle the fully correct arrow. There is some reason to suspect that this ability to correctly detect the direction of flight while in house B may have been due to the coincidence that the actual flight path and the imaginary line connecting the two open windows in house B happened to coincide. The critical factor appears to be the position of the windows.

TABLE 3

Mean Degree of Certainty in Reported Judgements

TRIAL	House A	House B	Mean
1	1.00	1.08	1.04
2	1.08	1.33	1.20
3	1.17	1.25	1.21
Mean	1.08	1.22	

Scale

0 = Uncertain
1 = Moderately Certain
2 = Quite Certain

Table 3 shows the degree of certainty felt by the subjects in making the judgements of directionality of the flyovers. Subjects were, on the average, more than moderately certain of the correctness of their judgements, despite the fact that the judgements were, for the most part, incorrect.

It appears on the basis of this preliminary investigation, that subjects are able to correctly detect the direction of aircraft flyovers only in certain houses and under certain fortuitous conditions. In other houses with different window openings, the subjects did not judge direction above the chance level.

An even more important finding, however, is the fact that the subjects were more than moderately certain that their judgements were correct. This would seem to indicate that they felt the aircraft had a specific direction of flight, however incorrect their judgements. Therefore, the sound tapes used in our laboratory should be tailored in such a way as to elicit similar responses from other subjects in subsequent experiments, i.e., subjects should feel moderately certain that they can guess the correct direction of simulated flyovers in our laboratory.

2. Localization of the Source of a Monophonic Signal Presented on a Four-Channel System

In the course of further attempting to recreate realistically the sounds of jet aircraft overflights, it was discovered that a monophonic recording of a jet take-off or landing, when presented through a four-channel system (one speaker in each corner of the room) gave the sensation that the sound was coming from a single source directly overhead. This seemed a rather interesting phenomenon, since the four speakers were below the level of the listeners' head.

When it was suggested that it was merely a matter of expectancy, a recording of a motorcycle was played and it also seemed to pass overhead. Monophonic recordings of the human voice were introduced and they also seemed to come from overhead.

The advantages of this effect for our laboratory were immediately apparent. It was clear that simulated aircraft flyovers would seem to be over the house, rather than under or through it. These conclusions were reinforced by the following experiment.

a) Procedure

Twenty-one male subjects ranging in age from 19 to 25, having hearing levels within 20 dB of ISO normal hearing, participated in the experiment.

The test room was the specially constructed double-wall IAC sound chamber which has already been described. It should be noted further that the chamber has sheetrock walls installed inside the room, and an acoustic tile ceiling, and wall-to-wall carpeting. Curtains covered simulated windows on two walls. In each corner of the room, which measures 18' x 14', was a Klipschorn speaker, which is about 36" high.

Subjects were brought individually to the laboratory and were blindfolded with opaqued sunglasses and rubber tape before being escorted into the test room.

They were told that they would hear a series of sounds which could come from anywhere around them, above them, under them, or even inside their own heads. They were asked to point to the apparent source of each sound as well as reporting verbally where they are pointing.

The subjects were then taken into the test room and required to stand in the center, facing in one of four directions, which were counterbalanced. They were instructed that they were allowed to turn their heads and torsos to localize the source of the sounds. 3 x 5 cards with numbers 1-27 were located in strategic places on the walls, floor and ceiling, so that the experimentor could record the direction in which the subject was pointing. The sound tape was then started.

The tape consisted of a series of sounds recorded on one, two, or four channels, in random fashion. Ten one-octave bands of noise with center frequencies ranging from 28.12 HZ to 14.4 KHZ were used as meaningless sounds, while jet takeoffs and landings and spoken voice were used as meaningful sounds. Sound Pressure Levels for each octave band were adjusted to give equal loudness for each sound, namely 20 sones (Stevens Procedure).

b) Results

Figure 11 shows the percentage of subjects reporting four-channel sounds as generally overhead and as directly overhead for each octave band of noise and for voice, take-off and landing. Although the results for voice are in agreement with those for bands of noise, notice that the airplane sounds are more frequently located generally and directly overhead. This may result from the influence of expectancy.

Figure 12 shows the average angle above the horizontal of the perceived sound source for one and two channel presentations. Strangely enough, most subjects perceived even single and dual channel presentations as coming from above the horizontal. This may be of help in explaining why we hear four channels as coming from above. Since the sound from a single speaker is localized as coming from about 20 degrees above the horizontal, two such sounds would be located between the two speakers but also about 20 degrees above the horizontal. When all four speakers are on, the front two sources are combined as just described as are the rear two speakers. The apparent source of the two front speakers is combined with the apparent source of the rear two speakers. The resultant apparent single source is midway between the front and rear sources, which are themselves resultants of separate sources. Whatever the correct explanation, the experiment amply demonstrated that the apparent source of a monophonic signal presented on a quadrophonic system is generally localized as coming from above.

The experiment was also partially conducted in an anachoic chamber. Bell Labs at Murray Hill, N.J., was kind enough to arrange for use of their anachoic chamber. Three subjects listened as honestly as possible and agreed that the effects noted in our laboratory study still seemed to be present.

3. <u>Test of Optimal Number of Flyovers Presented to Subjects Prior to Judgements of Annoyance</u>

In most psycho-acoustic laboratory tests, a subject is presented with a single stimulus and immediately asked to make a judgement or response. In the real environment, people do not usually judge each and every stimulus. They generally experience a wide variety of stimuli over a period of time and somehow integrate them into a summated response. The limits of about two hours time that subjects are usually willing and able to remain in a laboratory for an experimental session restricts the number of stimuli that can be judged in a laboratory program. Nevertheless, it was decided to test the stability of annoyance judgements in relation to a limited number of repeated exposures prior to a judgement. It was decided to omit one and two repetitions from the test and concentrate on three, four and five repetitions in this experiment.

a) Procedure

Twenty-four subjects who lived under actual JFK flight tracks participated in the experiment.

Two subjects at a time were taken to the living room chamber in twelve trials and asked to watch two standard comedy color TV shows and make judgements on the extent that the aircraft flyovers occurring during the programs interfered or annoyed them. The actual instructions are presented below and Figure 13 is a copy of the sheet used to record responses.

INSTRUCTION FOR EXPERIMENT ON EXPOSURES

"Good Morning, I am -----

Please go into the living room and be seated over here in the center of the couch. As you may know, Columbia University has an extensive environmental research program, of which our group is a part. We are interested in learning more about how people respond to different noises, especially those from airplane flyovers.

We are going to have a TV show for you to watch and we hope you enjoy it. From time to time you will hear airplanes flying over. Occasionally you will hear a voice from this speaker (point to front right facing door), asking you to record your response to the airplanes which you have just heard.

In the first column, I would like you to indicate the extent to which the aircraft flyovers interfered with your watching and listening to the TV program. In the second column, I would like you to indicate the extent to which they bothered or annoyed you.

There is no right or wrong answer -- We just want to know how you feel. You will notice on the right hand side of the sheet, a thermometer with numbers from 0 to 4. 0 means that the airplanes did not interfere at all or that you were not annoyed at all. 4 means that the interference or annoyance was very much. Any number in between would indicate that your feelings were something greater than 0 but less than the top category of 4.

Please also notice that there are 9 lines. There will be 9 different times when a voice will ask you to record your responses. You will not be required to do this after each aircraft flyover, but only when you hear a voice from the speaker. After each time you hear a voice asking you for your response, you will enter two numbers on each line to indicate how you feel about the amount of interference and annoyance with the aircraft sounds which you heard since the previous time you recorded your responses.

I would like you to remain seated until the end of the first session, which will be about 30 minutes. Then we will have a brief coffee-break. In all, there will be three 30-minute sessions. If at any time during the session you want to talk to me, for example; if the TV picture or sound goes off, you can do so by pressing the button on top of the TV speaker and talking to me."

To minimize fatigue, each trial was divided into three half-hour sessions. Refreshments were served between sessions and subjects moved about for about five minutes during each intermission. The interval between each flyover (peak to peak) averaged about 2½ minutes, (the usual frequency of operations at JFK). In order to equalize the time devoted to each number of repetitions, four judgements were made of each series of three flyovers, three judgements for four flyovers and two for five flyovers. The order of presentation of number of flyovers was randomized for each trial as follows:

Order of Trials

	Order
Trial 1 -	3 4 5
2 -	3 5 4
3 -	4 5 3
4 -	4 3 5
5 -	5 3 4
6 -	5 4 3

A recording at 1.1 miles from touchdown of a 727 landing with a peak of 80 dBA was used in all flyovers.

b) Results

No significant differences in mean annoyance responses were reported for the three numbers of repeated flyovers tested. A "t" test was used as the statistical measure of significance. As Table 4 shows, the differences among the means are very small. The probability that the mean of 3 repetitions could exceed the mean of 4 repetitions due to chance is about .35; the probability of the difference between 3 and 5 is .20 and for 4 vs. 5 is .70. Consequently, it was decided to use three repeated stimuli in future annoyance studies.

TABLE 4

Average Annoyance by Number of Repeated Flyovers Prior to Judgements

Number Flyovers	Average Annoyance
3	2.34
4	2.17
5	2.25

Our first substantive study of comparative interference and annoyance judgements of two proposed retrofit packages for the 727 airplane (JT-8 D engine) is now nearing completion and will be reported shortly. A few qualitative observations, however, can be made at this time regarding the new methodology described in this report. First, residents from a random sample of persons living under actual aircraft flight tracks can be induced to participate in a realistic laboratory experiment. There are many problems, but it can be done. Second, the simulated flyovers heard in the laboratory appear to be realistic to the subjects, with many subjects offering spontaneous comparisons of the laboratory flyovers with their usual real environment experiences. Third, subjects generally enjoy the TV task, laughing and talking about the program in an uninhibited way. Some subjects appear to be listening to almost every flyover and making notes of their perceptions, even though recorded judgements are made only after after each three flyovers. Others are following instructions more literally and simply record judgements when instructed to do so. Fourth, our initial study includes only persons with previously reported moderate fear of aircraft crashes. Feelings of misfeasance will vary and be treated as a co-variate in the analysis. Other studies will include other predispositional groups, so that it will not be possible to ascertain whether laboratory responses are related to real life predispositional differences until a full series of experiments are concluded.

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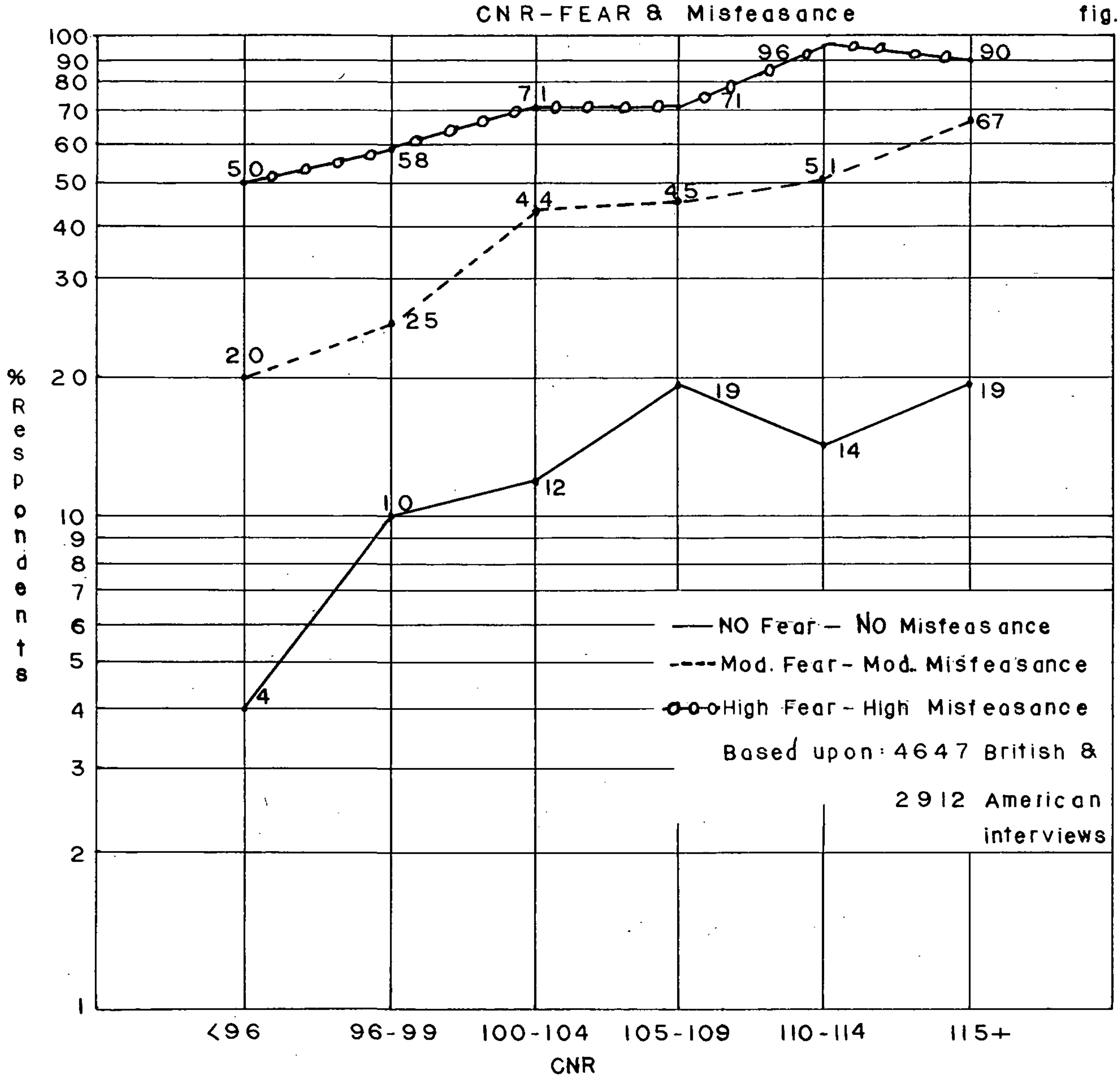
Reported High Annoyance with Aircraft Noise
by
CNR-FEAR & Misfeasance

fig. 1



Columbia University — Noise Research Unit
Dec. 1971

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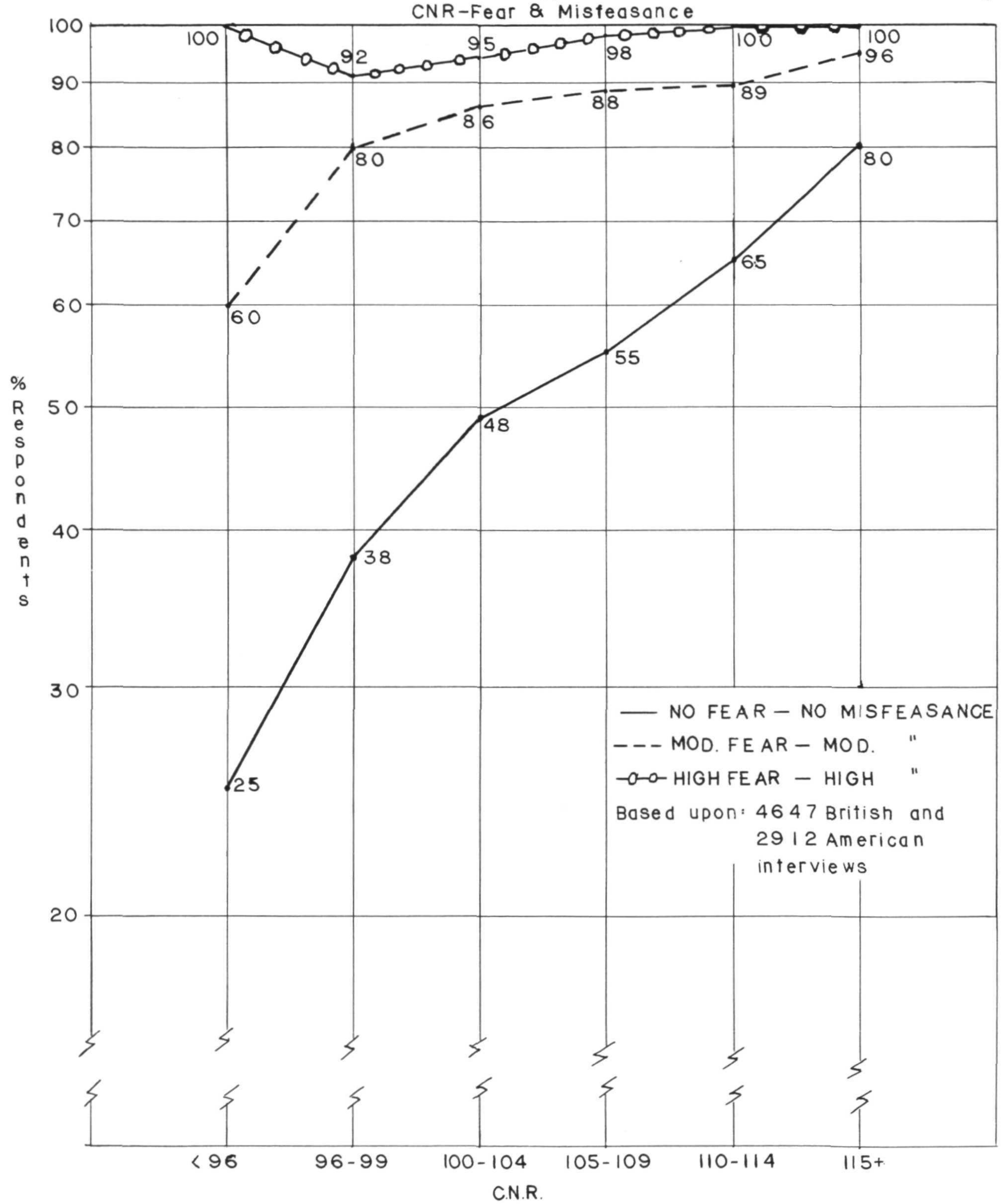
by
CNR-Fear & Misfeasance

fig. 2



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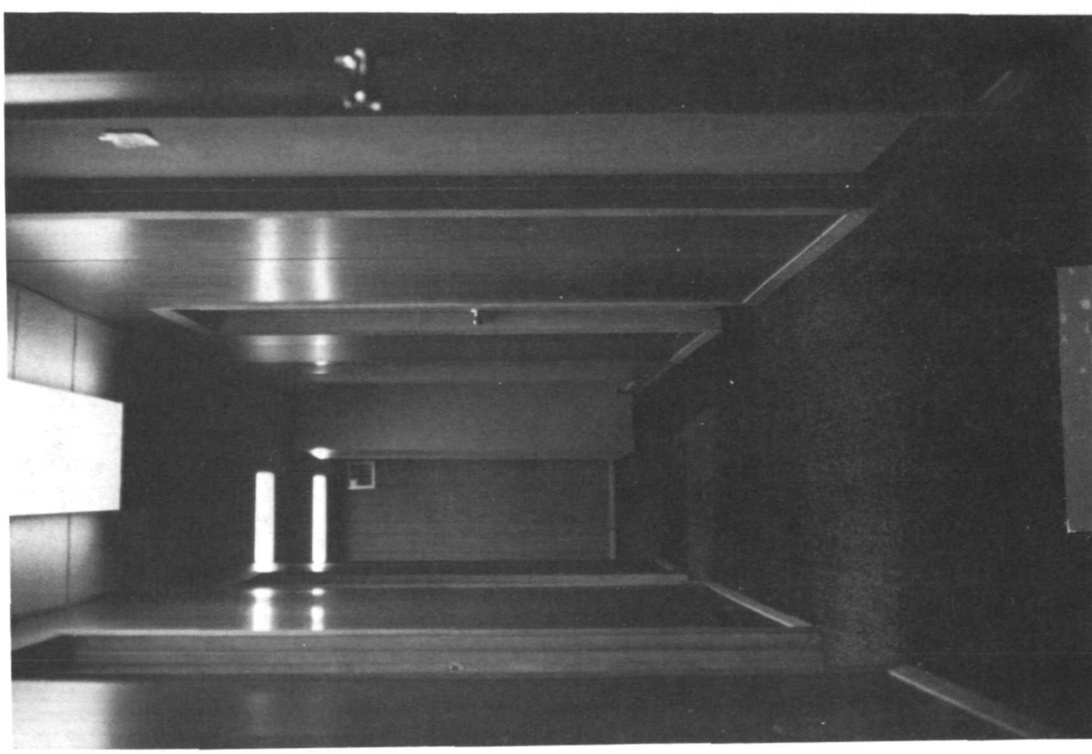


FIGURE 3

FIGURE 4

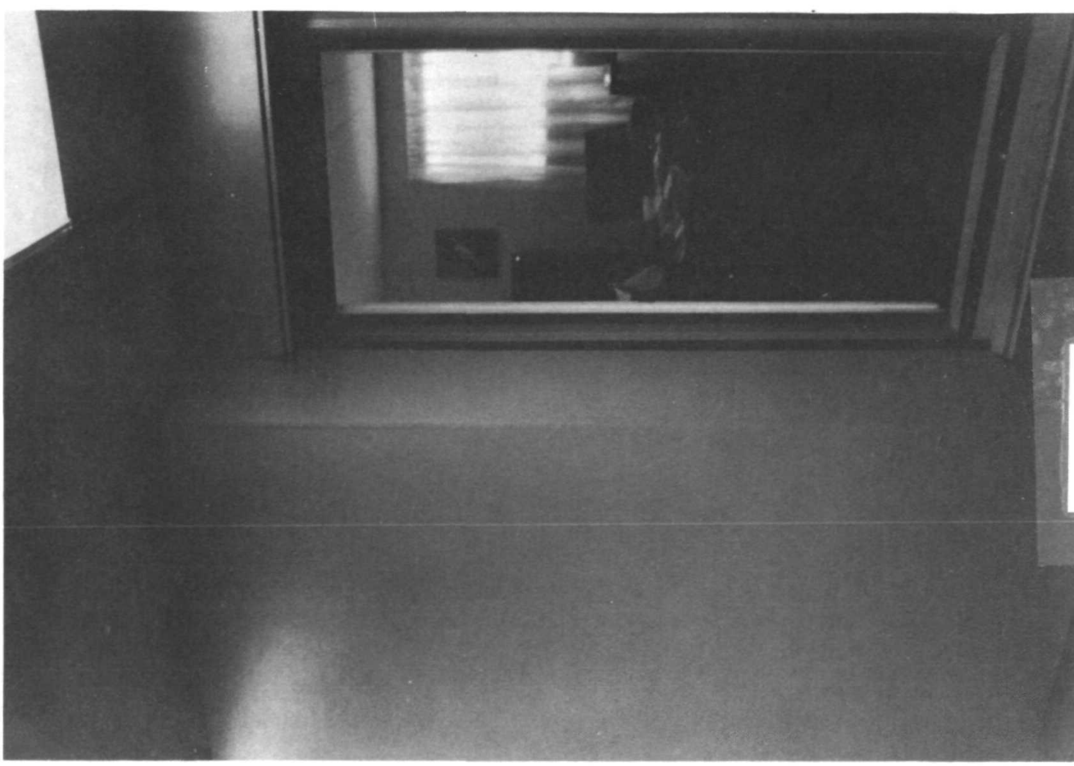


FIGURE 5

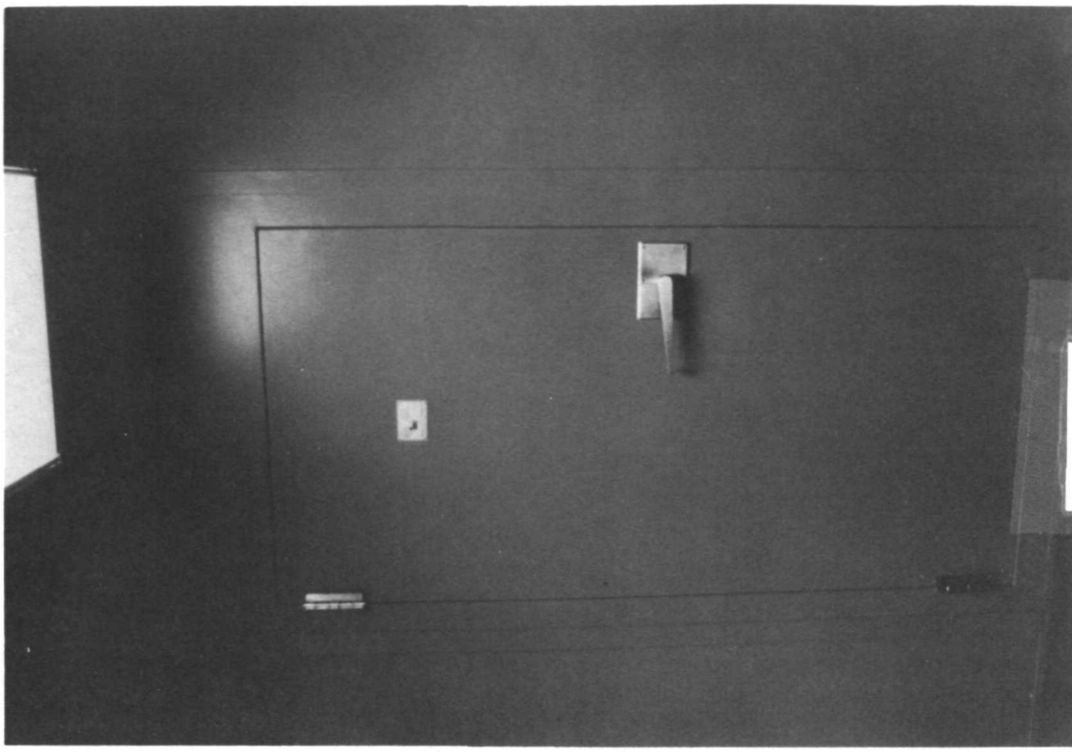


FIGURE 6

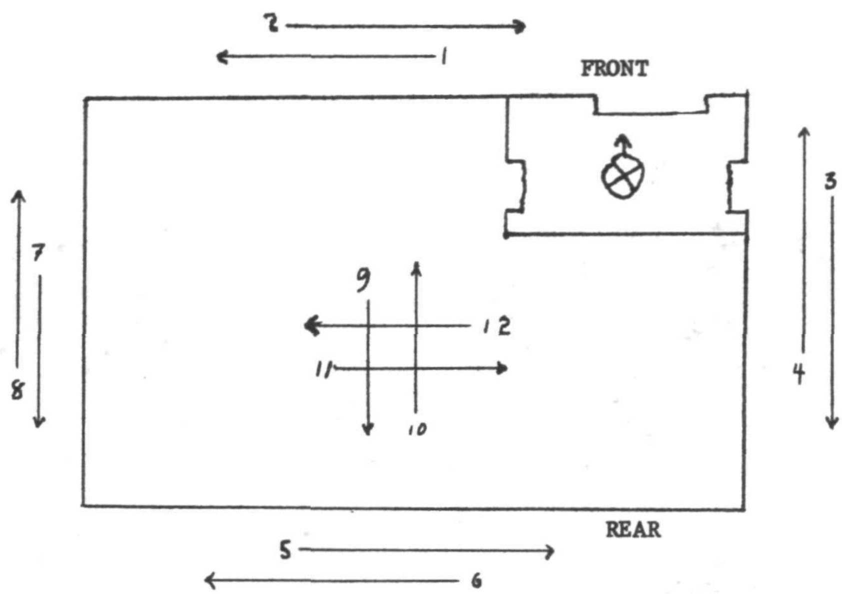
FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

DATA SHEET FOR DIRECTIONAL STUDY



How certain are you that your decision was correct? (Check One)

Quite Certain ( )
Moderately Certain ( )
Just Guessing ( )

Was the flight a take-off or a landing? (Check One)

Take-Off ( )
Landing ( )

Name:______________________________

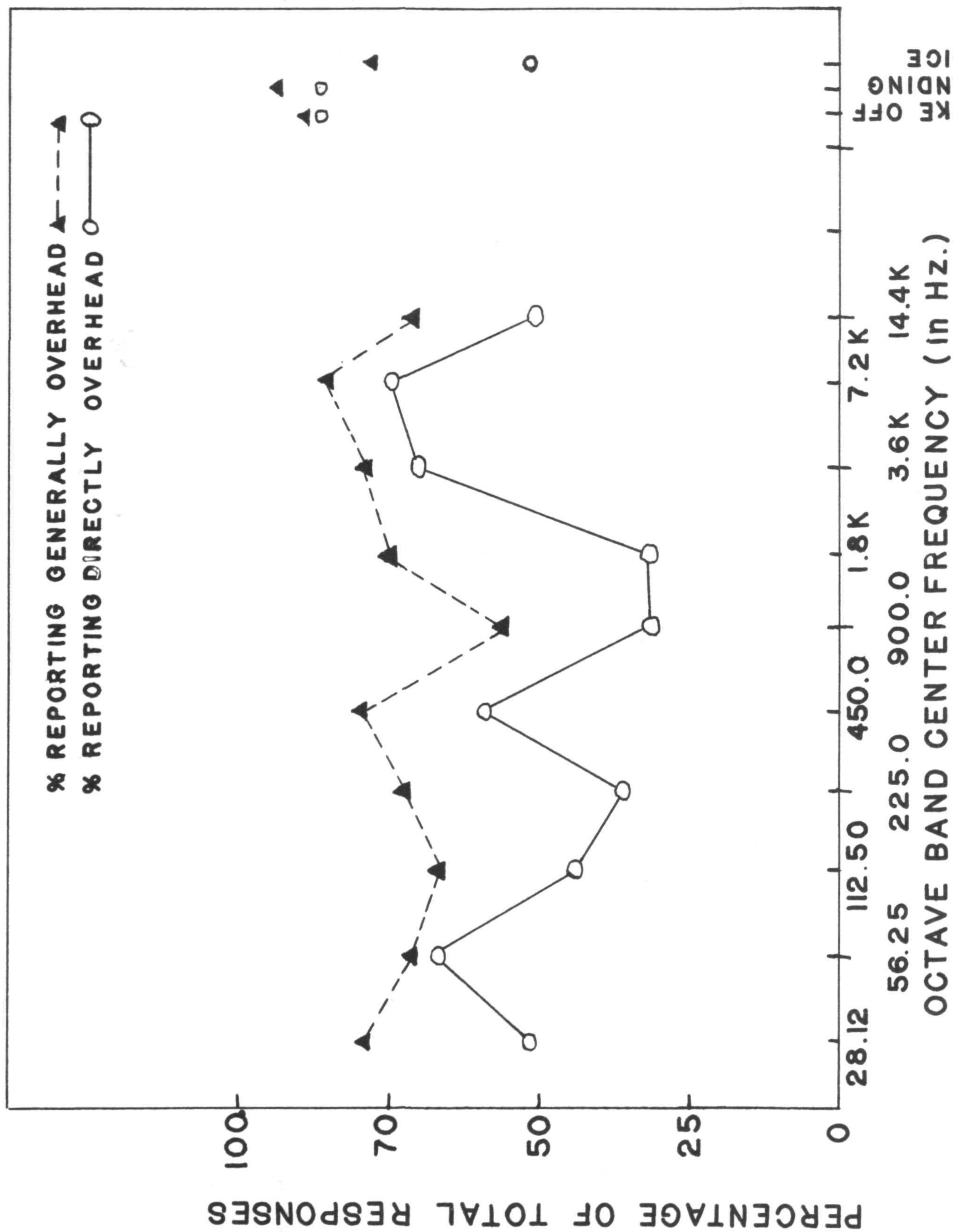
Date:______________________________

Hour:______________________________

House A:___________________________ First ( ) Second ( )

House B:___________________________ First ( ) Second ( )

Window: Closed ( )
Open ( )



% REPORTING GENERALLY OVERHEAD
% REPORTING DIRECTLY OVERHEAD
PERCENTAGE OF TOTAL RESPONSES
100
70
50
25
0
28.12
56.25
112.50
225.0
450.0
900.0
1.8K
3.6K
7.2K
14.4K
TAKE OFF
LANDING
VOICE
OCTAVE BAND CENTER FREQUENCY (in Hz.)

FIG. 11

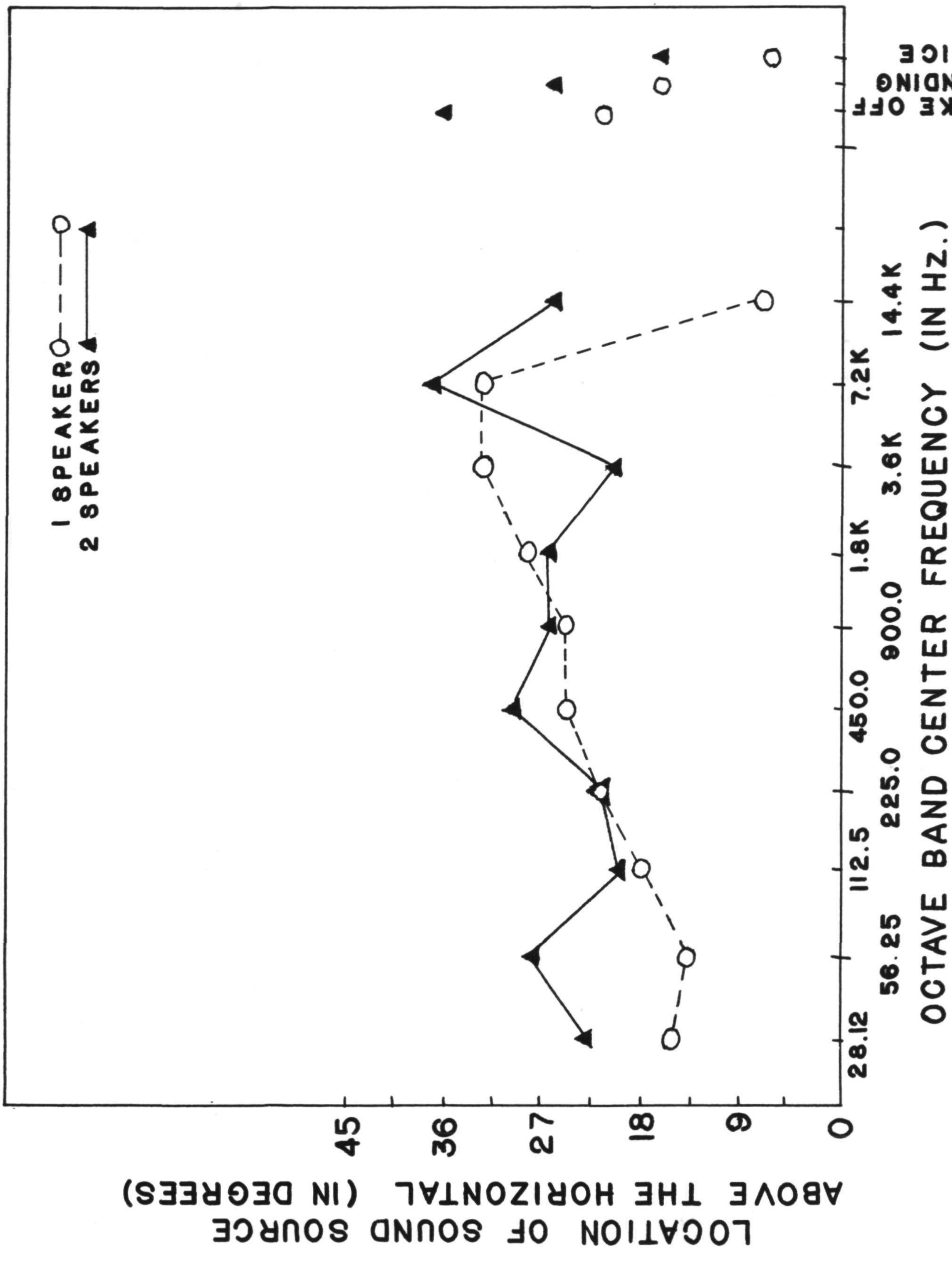

1 SPEAKER
2 SPEAKERS
45
36
27
18
9
0
LOCATION OF SOUND SOURCE
ABOVE THE HORIZONTAL (IN DEGREES)
28.12
56.25
112.5
225.0
450.0
900.0
1.8K
3.6K
7.2K
14.4K
TAKE OFF
LANDING
VOICE
OCTAVE BAND CENTER FREQUENCY (IN Hz.)

FIG.12

FIGURE 13

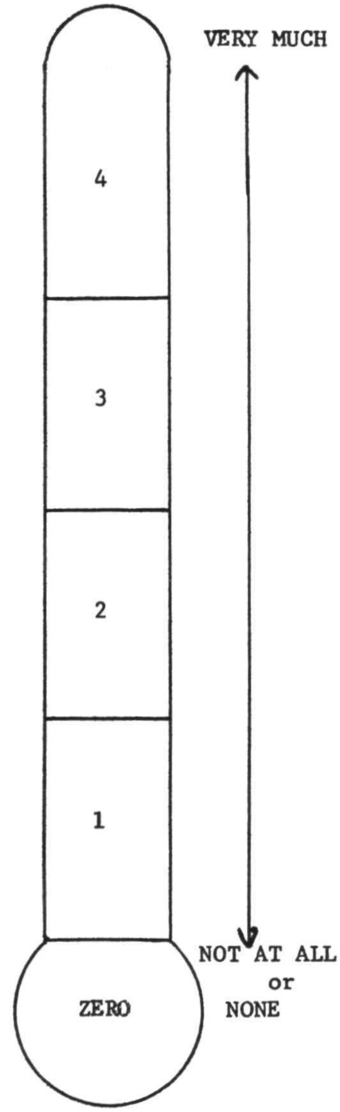
DATA SHEET FOR NUMBER OF EXPOSURES STUDY

DATE: ______________________________

NAME: ______________________________

ADDRESS: ______________________________
(Street) (Town)

	INTERFERENCE	ANNOYANCE
1		
2		
3		
4		
5		
6		
7		
8		
9		



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